Analysis of Stable Isotopes: From the Archaic to the Horticultural Communities in Central Chile

Author(s): Lorena Sanhueza and Fernanda Falabella
Source: *Current Anthropology*, Vol. 51, No. 1 (February 2010), pp. 127-136
Published by: The University of Chicago Press on behalf of Wenner-Gren Foundation for Anthropological Research
Stable URL: http://www.jstor.org/stable/10.1086/649055
Accessed: 06/10/2011 09:22

Reports

Analysis of Stable Isotopes: From the Archaic to the Horticultural Communities in Central Chile

Lorena Sanhueza and **Fernanda Falabella**

Departamento de Antropología, Facultad de Ciencias Sociales, Universidad de Chile, Ignacio Carrera Pinto 1045, 2do piso, Ñuñoa, Santiago, Chile (loresan@uchile.cl).
15 XI 08

Diet and mobility at the end of the Archaic period and the initial stage of the Early Ceramic period in central Chile are the subjects of this paper and are discussed on the basis of the results of stable isotope analysis of 20 individuals sampled from the Andean cordillera, central valley, and coast. The results indicate that the diet of Archaic groups living along the coast did not incorporate marine resources to any significant extent. Individuals sampled from the Early Ceramic period do not reveal consumption of animal protein, which raises the question of alternative sources for the protein necessary for survival. In terms of mobility, the results of the investigation suggest that the cordillera was occupied by people with a high-mobility pattern.

For some time, researchers have held a dichotomous vision of the Archaic and Formative periods throughout the Americas. The interpretation of prehistory in central Chile, in the southern part of the New World, is not unfamiliar with this paradigm. Consequently the Archaic period (11,000–400 BC) has become synonymous with hunters and gatherers with high mobility, whereas the period immediately following, the Early Ceramic period (400 BC–AD 1000), has implied a sedentary community with a horticultural subsistence and producing ceramics—an interpretation that was thought to be valid for the entire region (Falabella and Stehberg 1989).

Recently, this idea has begun to be modified. On one hand, evidence of cultigens such as quinoa (*Chenopodium quinoa*) is known from sites dated to the end of the Archaic (Planella, Cornejo, and Tagle 2005). On the other hand, there are groups attributed to the Early Ceramic period that neither became sedentary nor adopted horticulture (Cornejo and Sanhueza 2003). In light of new evidence provided by stable isotope analysis, the goal of this paper is to discuss diet and mobility at the end of the Archaic period and the initial stage of the Early Ceramic period.

 0011-3204/2010/5101-0020$10.00. DOI: 10.1086/649055

Background and Problems

A first problem of interest is to explore the dynamics of marine adaptation among Archaic groups. The available data from the few coastal sites investigated, such as Punta Curaumilla and LEP-C, suggest an initial coastal occupation (6850 BC at Punta Curaumilla) by inland groups of hunters and gatherers, which over time would become more habitual, utilizing a broader spectrum of coastal resources (Falabella and Planella 1991; Ramírez et al. 1991).

A second problem of particular relevance to this discussion is the mobility and diet of the Archaic III/IV groups (6000–400 BC). In the case of inland valley sites, Cuchipuy and Tagua Tagua II (at the southern extreme of the study area), the importance of local lacustrine resources, such as frogs, rodents, nutria, birds, fish, and freshwater mollusks associated with Lake Tagua Tagua, is evident, as is the importance of camelids (Durán 1980; Kaltwasser, Medina, and Munizaga 1980). In the northern section of the study area, in the Chacabuco area, Late Archaic sites are small and ephemeral, focusing on the exploitation of lithic quarries for raw material, consistent with a highly mobile settlement system (Hermosilla et al. 2003). Some sites, such as Vegas La Fortuna, have been associated with the occupations of Cuchipuy and Tagua Tagua II on the basis of stemmed and unstemmed lanceolate points (Jackson and Thomas 2000).

In the highlands, the Archaic III/IV occupations of El Manzano 1, La Batea 1, Las Morrenas 1, and Los Queltehues, among others, show evidence of repeated use of the Andes Cordillera between 1,000 and 3,000 m a.s.l., with an emphasis on the consumption of guanaco and a general use of fine-grained raw materials procured from highland sources (Cornejo and Simonetti 1997–1998). Although the precise range of mobility has not been defined for these groups, the possibility of a year-round human occupation of the Cordillera has been established, according to the reported ethnohistoric accounts at the moment of contact, describing the occupation of both sides of the Andes Cordillera by groups of hunters and gatherers (Madrid 1977).

If there is indeed evidence of some exotic highland resources, such as obsidian, at sites along the coast and in the lowland valleys (Cuchipuy, La Fortuna B, Las Cenizas) and evidence of marine mollusks in inland sites (Cuchipuy, Tagua Tagua II), published data fail to explain the contextual importance of these finds or the manner of their procurement (Durán 1980; Gajardo Tobar 1958–1959; Jackson and Thomas 2000; Kaltwasser, Medina, and Munizaga 1980). The subsistence of the hunter-gatherer undoubtedly implies a strategy of high mobility; however, from the available data it remains unclear whether this mobility is broad (at a regional level) or restricted (within a limited area). What is clearly expressed by the recovered ecofacts is that edible resources from each locality are being utilized. In the context of this discussion, one would expect marine resources to be consumed exclusively on the coast, with no consumption of these products in inland sites, as well as indications of occupation within circumscribed geographical areas.

A third problem to consider is the correlation between the incorporation of domesticates into the diet and the appearance of ceramics. In spite of the early presence of quinoa in sites in the Andes Cordillera, such as Las Morrenas 1, which dates to the Archaic period (Planella, Cornejo, and Tagle 2005), available data suggest a gradual incorporation of cultigens into the diet. This is verified in several contemporaneous sites in which some degree of horticultural activities may or may not be seen (Sanhueza, Vásquez, and Falabella 2003). This is especially apparent at the beginning of the Ceramic period, during the Initial Ceramic-Using Communities (ICC; Comunidades Alfareras Iniciales [CAI]; 300 BC–AD 200), where despite the presence of cultigens such as quinoa (Falabella and Stehberg 1989; Planella et al. 2006; Quiroz and Belmar 2004; Sanhueza and Falabella 1999–2000, 2003) and ceramics, the groups fundamentally maintained a hunting and gathering subsistence.

It is evident that the populations at both the end of the Archaic period and the initial Ceramic period were familiar with quinoa, although there is no way to measure the importance of this cereal in their diets, and it is very possible that its incorporation into the diet became increasingly important as the process of horticulture became more rooted in central Chile. For the purpose of our discussion, it remains to be confirmed whether a change toward sedentism is made in ICC sites, as would be expected from a community whose subsistence is based on horticultural productivity.

Finally, in terms of the Early Ceramic period sites in the Andes Cordillera, there are two problematic topics we must focus on: mobility and the incorporation of cultigens into the diet. It has been proposed that, contemporaneous to the horticultural producers of ceramics along the coast and in the lowland valleys (post AD 200), the highlands would have been occupied by groups of hunters and gatherers who maintained a settlement/subsistence pattern and a lithic technology similar to that of the Archaic period yet with the introduction of ceramic wares into the tool kit and, eventually, cultigens (Cornejo and Sanhueza 2003; Planella, Cornejo, and Tagle 2005).

Taking exception to this, the highland site of Chacayes yields an artifact assemblage that clearly places it within the Early Ceramic period; however, it cannot be attributed to the cordilleran hunters and gatherers nor can it be correlated to any of the cultural expressions defined for the region. Moreover, it suggests important parallels to the cultural manifestations of El Molle Culture further north (Sanhueza 1997; Stehberg 1978) and certain similarities to other southern highland sites south of the Río Cachapoal drainage (Falabella et al., forthcoming). Thus, we would expect differences between the hunter-gatherers from the "Archaic Tradition" and the groups that inhabited the site of Chacayes.

Isotopes, Diet, and Mobility

Enhanced by experimental research, the analysis of stable isotopes has established itself as an effective method to study diverse aspects of diet and human mobility, giving fresh meaning to the truism that we are what we eat. With respect to diet, analyses of isotopes help to distinguish (*a*) marine diets (which eventually led to littoral adaptations) from the terrestrial diets typical of inland inhabitants and (*b*) hunting-and-gathering diets from horticultural diets.

The distinction between marine and terrestrial diets can be observed in nitrogen and carbon isotopes, as both are enriched by the consumption of marine resources (Schoeninger, De Niro, and Tauber 1983). Analyzed isotopic data from central Chile (table 1) clearly demonstrate this tendency (Falabella et al. 2007). The dietary pattern of hunters and gatherers should be distinct from that of horticulturalists, first, by a major dependence on wild faunal proteins, which would be observed by enriched $\delta^{15}N$ values (see Hedges and Reynard 2007; Koch 2007; see Schwarcz, Dupras, and Fairgrieve 1999 for problems regarding this) and decreased $\delta^{13}C$ collagen-apatite spacing ($\Delta\delta^{13}C$col-ap; Bocherens 2000; Schwarcz 2000). Second, the distinction between hunters and gatherers and horticulturalists who consume maize can be seen by the marked enrichment of $\delta^{13}C$ in the latter. Since the C3 photosynthetic pathway is dominant in the wild vegetation of our Mediterranean-like study area—as is the case with all domesticated plants with the exception of maize (*Zea mays*), which is C4—this distinction is viable (Falabella, Planella, and Tykot 2008).

In discussing mobility, we will use $\delta^{18}O$ isotopic distinctions. Oxygen isotopes provide valuable information because of the topography of our study area. Central Chile has the advantage that in less than 200 km running east and west, groundwater originating from precipitation demonstrates great variation in $\delta^{18}O$, due to the significant increase in altitude and the drop in temperature as we move inland from the coast (fig. 1). A lineal latitudinal transect of 140 m of our study area shows a decrease in the average annual $\delta^{18}O$ from precipitation from −3.5‰ at the coastal margin to −17.3‰ at 4,200 m a.s.l. (Moser et al. 1972; fig. 2). The values increase again crossing the cordillera eastward to Argentina, where a mean $\delta^{18}O$ value of −5.7‰ has been reported for the city of Mendoza (827 m a.s.l.; Rozanski and Araguás 1995). These data confirm that $\delta^{18}O$ is sensitive to changes between coast and inlands and to the differences in altitude, enabling us to distinguish between peoples living in coastal, lowland valley, and highland environments. North-south mobility is also expressed in oxygen isotopes, but the differences are of less magnitude. Climatic variation, a source of change in the isotopic composition, should not affect this research since, with the exception of a single sample from Los Queltehues, the

Table 1. Average values and standard deviation of different resource categories analyzed in central Chile

Resource	*n* (sample)	*n* (species)	$\delta^{13}C$	$\delta^{15}N$
Coastal lacustrine fauna	2	2	−22.9 ± .8	7.1
Inland lacustrine fauna	1	1	−16.0	2.1
Marine mammal	1	1	−11.7	20.2
Marine fish	5	5	−13.7 ± 1.7	16.7 ± 2.6
Marine mollusks	4	4	−15.3 ± 1.6	15.9 ± 1.5
Marine algae	2	2	−15.7 ± 2.3	
Terrestrial fauna (guanaco)	6	1	−19.5 ± .6	5.0 ± .9
C3 wild vegetation	14	11	−26.6 ± 2.9	
C3 cultigens	6	6	−26.6 ± 1.6	
C4 cultigens (maize)	1	1	−11.2	

Note. Lacustrine fauna: *Myocastor coipus*, *Caudiverbera caudiverbera*; marine mammal: *Otaria* sp.; fish: *Cilus gilberti*, *Aplodactylus punctatus*, *Trachurus symmetricus*, *Merluccius gayi*, *Micropogonia furnieri*; marine mollusks: *Tegula atra*, *Choromytilus chorus*, *Mesodesma donacium*, *Concholepas concholepas*; marine algae: *Durvillea antartica*, *Porphyra columbina*; terrestrial fauna: *Lama guanicoe*; C3 wild vegetation: *Nasella chilensis* (Trin), *Puya* sp., *Peumus boldus*, *Cryptocaria alba*, *Brodiaea porrifolia*, *Schinus latifolius*, *Jubaea chilensis*, *Prosopis chilensis*, *Luma apiculata*, *Madia sativa*, *Aristotelia chilensis*; C3 cultigens: *Solanum maglia*, *Lagenaria* sp., *Solanum tuberosum*, *Chenopodium quinoa*, *Cucurbita* sp., *Phaseolus* sp.; C4 cultigens: *Zea mays*. For sample details, see Falabella et al. (2007:9).

conditions in temperature and precipitation remained stable throughout the period under investigation (Jenny et al. 2002; Villa-Martínez 2002).

Most of the water necessary for human organism is consumed on a daily basis, such that the bone $\delta^{18}O$ fundamentally reflects the value of the water consumed (Schoeninger, Kohn, and Valley 2000). While the O isotope fractionation is impacted by environmental conditions as well as physiological factors, progress in identifying these fractionations (Levinson, Luz, and Kolodny 1987; Longinelli 1984; Luz, Kolodny, and Horowitz 1984) has enabled the incorporation of the $\delta^{18}O$ of phosphates and carbon structures in provenience studies (Bentley et al. 2007; Budd et al. 2004; Ehleringer et al. 2008; Schwarcz, Gibbs, and Knyf 1991; White et al. 2004, 2008).

Methodology

Analyzed samples consist of both male and female adult femoral cortical bone, with the exception of Chacayes sample 2, which consists of a mandible (table 2). This element was chosen for its density as well as its lesser propensity to diagenetic contamination. The carbon and nitrogen of collagen (organic matrix of bone) and the carbon and oxygen of structural carbonate in apatite (mineral matrix of bone) were analyzed. Both collagen and apatite are constantly replaced throughout the individual's lifetime in such a way that the bone's isotopic composition reflects the average diet of the latter years of the individual's life (Richards and Hedges 1999).

Analytical procedures were performed under the supervision of Dr. Robert H. Tykot, following well-established protocols, in the Laboratory for Archaeological Science at the University of South Florida (Tykot 2004). For extracting collagen, the bone sample was cleaned and soaked in 0.1M NaOH for 24 h to remove humic acids. Repeated removal of mineral bone (apatite) was done with 2% HCl; humic acid contaminants were further removed with 0.1M NaOH for 24 h and the fat content with a defatting solution. Collagen pseudomorphs were analyzed with a CHN (carbon, hydrogen, nitrogen) analyzer as well as a Finnigan MAT mass spectrometer for stable isotopes. The integrity of the sample was assessed visually with the resulting pseudomorphs, checking that the percentage of collagen output was >1% and that the measure of CO_2 and N_2 produced in the mass spectrometer was adequate.

For the extraction of carbonate from apatite, the sample was cleaned ultrasonically and crushed, sifted, and sorted centrifugally. The collagen was removed, repeatedly soaking the bacterial and humic proteins with 2% bleach solution. Bone was treated with 1 mL of 1M acetic acid sodium acetate solution for 24 h to remove nonbiogenic carbonates. Experimentation has demonstrated that this will remove the contaminant without any significant alteration of the carbonate structure. The samples were analyzed using a Finnigan MAT mass spectrometer coupled with a Kiel III device. The analytical mass spectrometry precision is ±0.1‰ for carbon and ±0.2‰ for nitrogen. The $\delta^{13}C$ and $\delta^{18}O$ results were reported in relation to the Pee Dee belemnite standard, and $\delta^{15}N$ is reported in relation to the international AIR standard.

The reconstruction of subsistence and mobility depends on

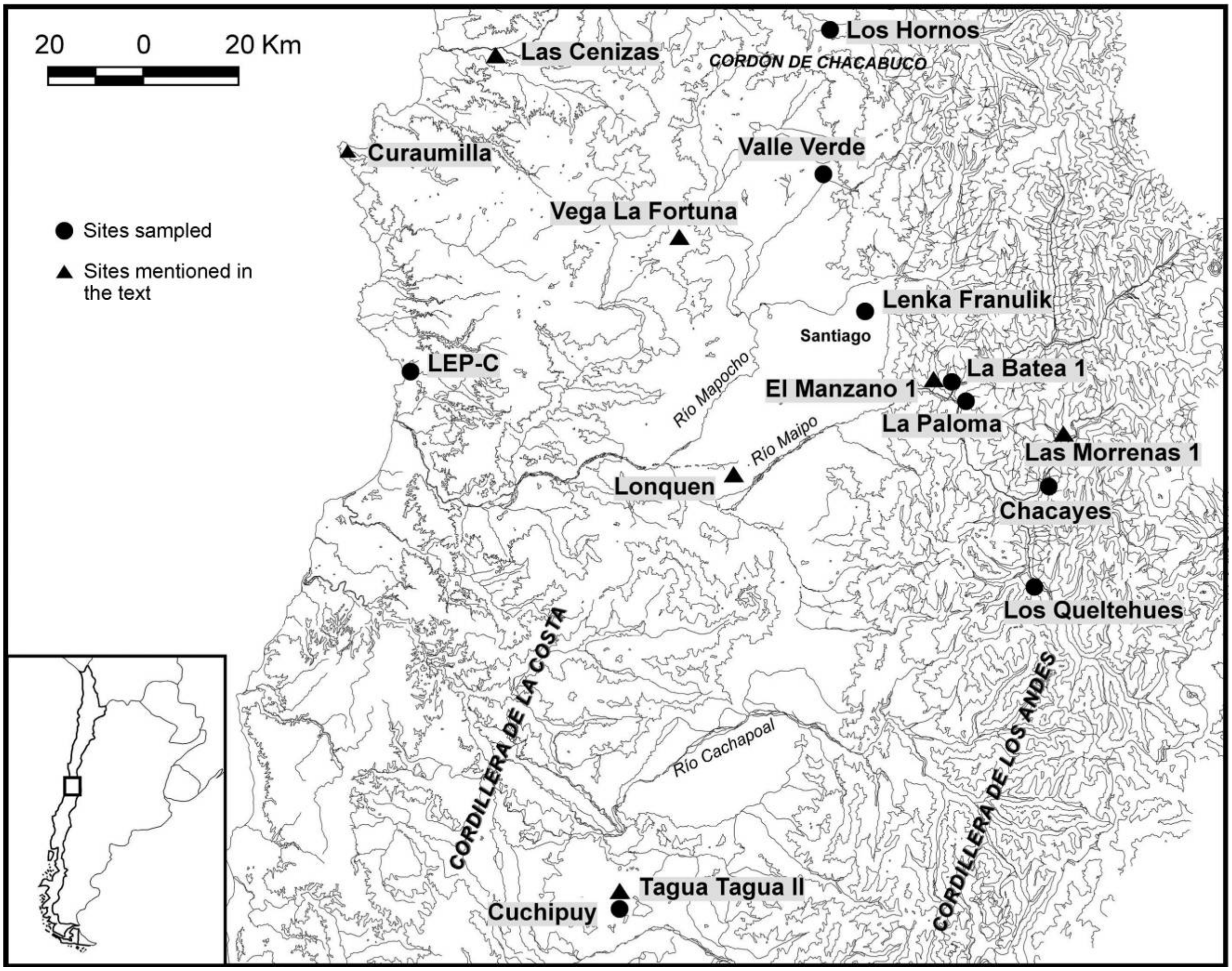

Figure 1. Distribution of archaeological sites in central Chile from which osteological samples were obtained.

the retention of the original biogenic indicators in bone. In the case of apatite, the comparison between teeth (which are less exposed to diagenesis) and bones from the same individuals shows a correspondence between them and leads us to believe that the processing procedures were adequate and that the structural indicators of carbonate yield reliable results (Falabella et al. 2007). While we cannot completely rule out diagenetic contaminations in the case of ^{18}O, we believe that if these were to exist, they would not obscure the differences between individuals who drank water with markedly different isotopic values.

Results and Discussion

With the exception of two cases in which reliable collagen was not obtained, the 20 individuals sampled from nine archaeological sites (table 2) provided material without evidence of diagenetic changes. These samples are not considered to represent whole populations but only individuals. While the number of samples available for analysis is small, the results allow us to discuss the hypotheses that have thus far attempted to explain the subsistence and mobility of these groups and to review, from a new perspective, the data that were used to formulate them.

Our first result is the apparent nonexistence of a marine-based diet during the Archaic period. Archaic peoples from the coast have $\delta^{13}C$ and $\delta^{15}N$ values, which indicate that marine resources were not a regular part of their diet (table 2). Marine fauna, including those from lower trophic levels, have much higher $\delta^{13}C$ and $\delta^{15}N$ average values than the four sampled individuals (table 1). People who consume these types of resources have both enriched C and N due to the baseline values of marine fauna and the N isotope fractionation that occurs with each trophic level (+3‰), even though these resources do not constitute 100% of the diet. Archaic period Chinchorro populations of the northern coast of Chile give clear examples of this ($\delta^{15}N$, 23.0‰; $\delta^{13}C$ collagen (Ccol),

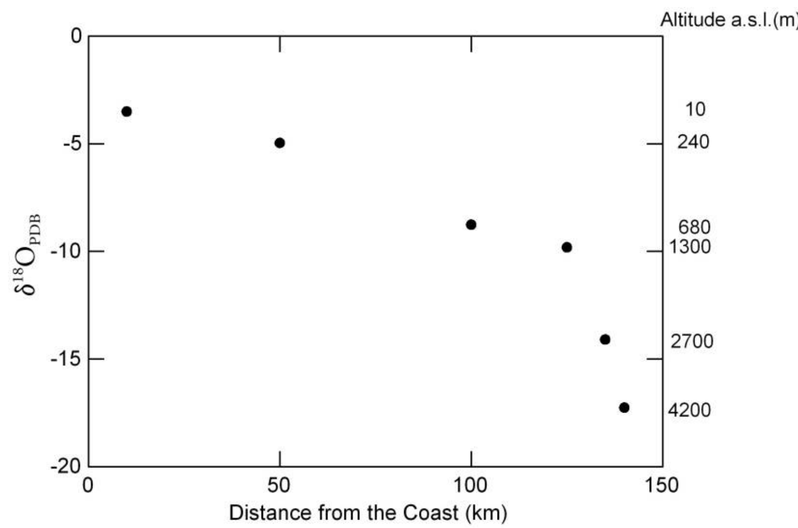

Figure 2. Variation in $\delta^{18}O_{SMOW}$ of the average annual groundwater from precipitation from the coast to the cordillera, relative to the increase of altitude above sea level (adapted from Moser et al. 1972). SMOW = standard mean ocean water.

−11.9‰), as well as people along the Patagonian coast line (δ^{15}N, 20.0‰; δ^{13}Ccol, −12.1‰), yielding isotopic values that leave no doubt that marine resources were consumed (Tieszen, Iversen, and Matzner 1992; Borrero and Barberena 2006). On the other hand, results from analyzed individuals from central Chile (δ^{15}N ranging from 7.0‰ to 13.1‰; δ^{13}Ccol ranging from −17.6‰ to −19.8‰) suggest that consumption of marine resources was at best occasional or circumstantial and cannot in any way be considered to reflect a "marine adaptation."

These results are consistent with the expectations for the earliest coastal occupations, which had been interpreted as representing initial contact by inland hunters and gatherers, as is the case for individuals of the earliest phase of site LEP-C (samples 1 and 18; Ramírez et al. 1991; Falabella and Planella 1991). This is not expected for individuals of later time periods (represented by samples 3 and 7), for which we had expected strong indicators of a marine diet. Our results show values of a predominantly terrestrial diet for individuals 1 and 3. The other two samples (7 and 18) show a slight increase in both the Ccol and N as well as less collagen-apatite spacing, reflecting a minor contribution of marine protein to the diet as well as individual variability.

The proposal of a marine-based diet was based on both the existence of sites on the coast and the presence of mollusk shells—which increased in size after the initial phase—as well as on fish and marine mammals in site refuse. Our sample includes only four individuals, and our results suggest that this evidence is not sufficient to infer a "marine adaptation." The abundant presence of mollusks in sites evidently indicates that they were consumed at some time, but their great "visibility" in the archaeological record has led to an exaggerated emphasis of their importance in the diet. Along these lines, from the isotopic values obtained for the Archaic period, it is more reasonable to propose a very occasional utilization of marine resources, more in keeping with the idea of circumstantial procurement based on availability (e.g., oyster [*Argopecten purpurata*] embankment) rather than a well-developed procurement strategy. In fact, there is no record of a specialized technology for the exploitation of marine resources for the coastal sites of central Chile, such as is observed at Norte Chico or on the southern coast (Llagostera 1989; Quiroz and Sánchez 2004); the only examples of fish hooks and net sinkers are found for later time periods. Of course, we cannot generalize that this situation applies to other coastal settlements on the basis of four individuals from a single site, but we would like to emphasize that this isotopic analysis is consistent with the data from Archaic artifactual assemblages in central Chile.

Reviewing the results of δ^{18}O values (table 2; figs. 1–3) is even more surprising. These are entirely consistent with the expectations for peoples who regularly ingest local waters from the coast ($\delta^{18}O_{SMOW}$, −3.5‰ [SMOW = standard mean ocean water]) and very different from the expectations for peoples who move between coast and inland, where the values for water are substantially lower (Moser et al. 1972). The data suggest that these four individuals who, contrary to what had been assumed, did not in fact come from the central inland area but rather spent at least the latter years of their lives living on the coast. The consistency of the value of the δ^{18}O of bone samples with that of local waters, however, opens up

Table 2. Isotopic indices for analyzed individuals

Context, site, individual no.	Sex	Date (of individual and site)	δ^{13}Ccol	δ^{15}N	δ^{13}Cap	δ^{13}Ccol-ap	δ^{18}O
Archaic, coast:							
LEP-C-1	M	pre-2000 BC	−19.4	9.0	−11.5	7.9	−4.1
LEP-C-3	F	2000–300 BC	−19.8	7.0	−11.2	8.6	−3.8
LEP-C-7	M	2000–300 BC	−17.9	11.7	−11.8	6.1	−2.4
LEP-C-18	F	pre-2000 BC	−17.6	13.1			
Archaic, lowland valleys:							
Cuchipuy-2	F	5000–2500 BC	−18.5	12.8	−11.0	7.5	−5.0
Cuchipuy-3	M	5000–2500 BC	−19.1	11.0	−11.3	7.8	−5.1
Archaic, highlands:							
Los Hornos	M	*2620–2460* cal. BC	−17.7[a]	n/d	−11.4	6.3	−5.4
Queltehues	n/d	5255–4785 BC	−17.9	3.9	−9.4	8.5	−7.2
La Paloma	F	1425–1190 BC	−19.2	7.6	−12.5	6.7	−4.8
ECP lowland valleys:							
Lenka Franulic-1	M	*170* BC–*130* cal. AD	−20.9[a]	n/d	−11.9	9.0	−9.3
Valle Verde-2	F	400 BC–AD 200	−20.1	5.5	−10.0	10.1	−8.5
Valle Verde-5	F	400 BC–AD 200	−19.8	4.3	−12.8	7.0	−8.2
Valle Verde-6	M	*370–110* cal. BC	−20.3	3.8	−13.5	6.8	−8.8
Valle Verde-7	n/d	400 BC–AD 200	−20.3	4.1	n/d		n/d
Valle Verde-9	F	*390–180* cal. BC	−20.2	4.1	−12.3	7.9	−9.0
Valle Verde-12	M	400 BC–AD 200	−19.6	5.2	−12.7	6.9	−9.3
Cuchipuy-1	M	ca. AD 600	−15.2	7.2	−9.8	5.4	−5.9
ECP highlands:							
La Batea	F	60 BC–AD 1035	−19.7	3.8	−13.5	6.2	−5.1
Chacayes-1	n/d	*680–900* cal. AD	−18.6	7.6	−10.3	8.3	−9.2
LICP highlands:							
Chacayes-2	M	*1310–1460* cal. AD	−11.3	5.6	−6.7	4.6	−7.5

Note. δ^{13}Ccol is the collagen value, δ^{13}Cap is the bone apatite value, Ccol-ap = Ccol-apatite, n/d indicates that no data is available; and italicized date indicates individual's accelerator mass spectrometry (AMS) date. ECP = Early Ceramic period, and LICP = Late Intermediate Ceramic period.
[a]*d* value obtained from the AMS dating lab.

the possibility of diagenetic contamination, which should be further examined in the future.

For the moment, these data present a scenario that is particular to central Chile, where there would have been populations occupying the coast without developing a marine adaptation per se and with mobility that would not have included inland forays. In this manner, one might posit a north-south movement along the coast; however, comparisons of the technological differences between assemblages from central Chilean contexts to those from coastal sites farther north and farther south, do not support this idea. Thus, it is likely that coastal hunters and gatherers of this period had developed a subsistence pattern with movement confined to areas directly adjacent to the coastline, using a broad range of available terrestrial resources in that area.

The relatively restricted east-west movement suggested by the results of the coastal δ^{18}O samples is conducive to a discussion of a second problem relevant to this paper: the settlement pattern of hunters and gatherers during the Archaic period in general.

Contrary to the coastal pattern, the values of δ^{18}O for bones analyzed for three individuals from sites in the Andes Cordillera are very disparate, with a range between −4.8‰ and −7.2‰ (table 2; fig. 3). These values have far greater positive values than those of the lowland samples, and they are considerably distant from the values of the highland waters ($\delta^{18}O_{SMOW}$ between −9.8‰ at 1,300 m a.s.l. and −17.3‰ at 4,200 m a.s.l.; fig. 2; Moser et al. 1972). Unlike the coastal data, these results cannot be attributed to sample contamination; all indicators point to the fact that the bones do not correspond to local waters. This suggests that these three highland individuals were only occasional inhabitants of the Cordillera and that the water they customarily drank had different characteristics. That is to say, they must have either traveled through different regions or inhabited different places during variable time periods. The range of travel could have been either eastward or westward, since both directions feature enriched δ^{18}O.

The values of δ^{15}N also are disparate (table 2). Nitrogen is highly sensitive to climatic change, as well as to such variables as altitude and latitude. A very low value, such as that recorded for the Queltehues sample (δ^{15}N, 3.9‰), together with a high $\Delta\delta^{13}$Ccol-ap (8.5), at first glance indicates a low consumption of meat. On the other hand, the enrichment of C is in both the collagen and the apatite, which would indicate a more enriched diet than the one we have attributed to the wild resources of central Chile during this time period. These values, thus, can be associated to a different climate, such as the

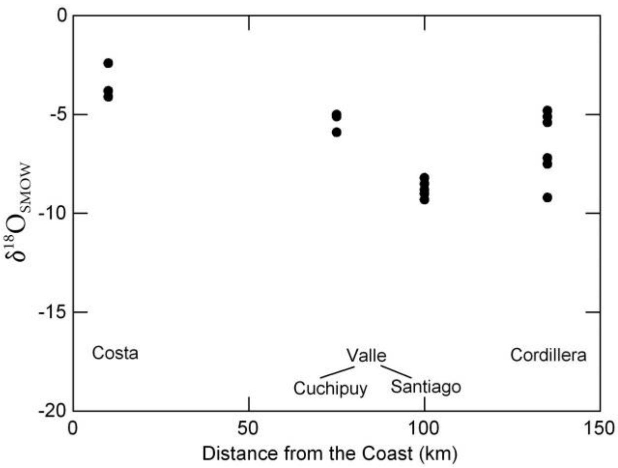

Figure 3. $\delta^{18}O_{PDB}$ values for bone samples from the coast (LEP-C, Archaic period), lowland valleys (Cuchipuy, Archaic, and Early Ceramic periods), the Santiago valley (Lenka Franulic and Valle Verde, beginning Early Ceramic period, corresponding to the Initial Ceramic-using Communities), and highlands (various Archaic, Early Ceramic, and Late Intermediate sites). PDB = Pee Dee belemnite.

drier and warmer environment in central Chile circa 5000 BC, or perhaps with the consumption of low-trophic-level marine resources (e.g., marine algae), that would increase the value of δ^{13}C but maintain a low value of δ^{15}N.

The sampled individual from Los Hornos has an enriched δ^{13}Ccol (−17.7‰) but an impoverished δ^{13}C apatite (Cap; −11.4‰). Further, this sample has an isotopic profile much like LEP-C-7, and the δ^{18}O −5.4‰ is compatible with temporary coastal habitation with consumption of marine proteins. Unfortunately, we have no data for N, which would have enabled us to confirm this hypothesis.

With respect to the inland valleys, the results for the Archaic-period individuals from Chuchipuy indicate a diet with enriched N resources and the value of O is consistent with the values expected from local sources of water. This suggests a more limited mobility, perhaps determined by an abundance of resources associated with a lacustrine ecosystem in the vicinity of the site. An alternate interpretation is that the enriched value of N is due to a settlement system that includes the coast, as was proposed some time ago by Núñez (1983), however, the consumption of freshwater species is more consistent with the archaeofaunal remains recovered from the site (Kaltwasser, Medina, and Munizaga 1980).

A third result relates to the inclusion of cultigens into the diet. For the ICC samples, the values of δ^{13}Ccol (between −20.9‰ and −19.6‰) as well as of δ^{13}Cap (−13.5‰ and −10.0‰) indicate that there was no consumption of C4 plant species, determining that maize definitely played no part in the diet for these populations. This is consistent with the results of archaeobotanical analyses, which have identified quinoa as the only domesticated resource in use during this time period. The low values of δ^{15}N (between 3.8‰ and 5.5‰) rule out the use of marine or lacustrine resources and further indicate that these groups consumed practically no meat or at least that animal protein was not a significant part of the diet, a fact that is corroborated by an especially high δ^{13}Ccol-ap spacing. Thus, a predominantly vegetarian diet is attributed to these people.

Because humans need a minimum amount of protein, this posits an important question with respect to nutrition, since in this case protein was not derived from high-quality animal sources. Consistent with this scenario is the presence of quinoa—a plant known to have a high concentration of protein (between 11% and 21%) and a combination of amino acids that is adequate for human nutrition. Other wild legumes such as algarrobo (*Prosopis chilensis*) were available sources of protein and might have obscured the evidence of meat consumption; algarrobo seeds have 32% protein and they also decrease the δ^{15}N for the consumer.

Thus, we attribute an essentially vegetarian diet to the ICC populations, which is different from the Archaic pattern. Not only is the consumption of animal protein decreased, but it also is likely that quinoa may have had a greater importance to the diet than archaeobotanical studies have suggested. This must have been accompanied by changes in the patterns of mobility as well as in the frequency of movement. In this respect, the O results are clear. The values from the different individuals are homogeneous (ranging between δ^{18}O −8.2‰ and −9.3‰), which is expected for populations that consistently use a single water source (Longinelli 1984; White et al. 2004) and, further, is consistent with what is expected for persons who drink water from the Santiago basin, from which our samples were collected (figs. 1–3). We have no way to determine whether this reflects sedentarism itself or a restricted mobility within a limited geographical area from which these isotopic values of water would be derived. However, the practice of horticulture is consistent with reduced mobility involving either of these possibilities. The cultivation of quinoa does not impose the same restrictions as growing other crops (e.g., corn) that require continuous care, but one needs to find and prepare an adequate place for its cultivation and return cyclically to harvest it at certain times of the year (Falabella, Planella, and Tykot 2008); this would anchor a population to certain parts of the landscape.

The change in diet observed toward the end of the first millennium BC may have had its origin in various environmental and social situations. Paleoenvironmental data for the region do not indicate any changes that might have impacted the availability of resources during this time period (Jenny et al. 2002) nor, at least in the highlands, is there any evidence of a decrease in fauna, such as guanaco, (L. Cornejo, personal communication). What does remain clear, however, is that the appearance of pottery—represented in the ICC populations—is not associated with a widespread horticultural process in central Chile and that horticulture at this particular time seems to have been restricted to quinoa.

Despite being based on a sample of only two individuals

(La Batea and Chacayes), the last point we would like to emphasize is that maize was not consumed regularly by all peoples in the Andes Cordillera during the Early Ceramic period after AD 200, despite the proximity of maize-eating and non-maize-eating populations. This suggests that some groups continued the traditional hunting and gathering subsistence during later times. The La Batea sample shows a hunter-gatherer isotopic profile with a C3 diet (δ^{13}Ccol −19.7‰ and δ^{13}Cap −13.5‰). On the other hand, the δ^{15}N (3.8‰) and δ^{18}O (−5.1‰) suggest mobility and only occasional highland occupation. The sample from Chacayes shows slightly more enriched values (δ^{13}Ccol −18.6‰ and δ^{13}Cap −10.3‰), especially in apatite, that denote occasional supplements of C4 plants and a δ^{15}N value (7.6‰) that is consistent with consumption of animal protein. This fact changes within this same highland area, at least for some individuals in the Late Intermediate period (AD 1000–1450), as observed in the results for the sample from the latest period at Chacayes, which show abundant consumption of C4 plants similar to contemporaneous populations in the lowlands (Falabella et al. 2007). While N decreases, the small collagen-apatite spacing suggests that animal protein persists in being a substantial dietary component. The values of δ^{18}O for the two Chacayes individuals are different from each other and show disparity between other cordilleran samples and are lower than would be expected for people who permanently live in the highlands.

Conclusions

It has become evident that the analysis of stable isotopes has the potential to address issues much broader than diet and the introduction of maize. The interpretations presented here have initiated a discussion on a range of topics relevant to understanding the sociocultural dynamics of groups that occupied central Chile during the Archaic period and the beginning of the Early Ceramic period. Topics such as marine adaptation, the beginnings of food production, and the contemporaneous practice of two different subsistence strategies during the Early Ceramic period have been reexamined and reconsidered, notwithstanding our analysis being based on a very small sample. Isotopic results have shown that Archaic populations from the coast, while living near the sea, did not develop a marine subsistence altogether, but incorporation of marine resources into the diet was occasional and variable.

We have provided evidence of restricted mobility within certain environments for populations living on the coast and lacustrine areas of the lowlands. On the other hand, we have identified a greater mobility for hunter and gatherers inhabiting the highlands only seasonally. Our results have supported the onset of sedentarism in the lowlands for the early horticultural populations and have provided data on their probable dietary sources. And finally, we have demonstrated the coexistence of hunters and gatherers with horticultural groups.

In so doing, we have outlined a direction for future research that should involve analysis of a larger sample of individuals from the Archaic period and the initial stages of the Early Ceramic period, as well as of populations that inhabited the highlands. This will provide us with a more solid basis to evaluate these results, determining whether they characterize the time period or merely represent anomalies.

Acknowledgments

This research was supported by Fondo Nacional de Desarrollo Científico y Tecnológico grant 1040553.

References Cited

Bentley, R. A, N. Tayles, C. Higham, C. Macpherson, and T. C. Atkinson. 2007. Shifting gender relations at Khok Phanom Di, Thailand: isotopic evidence from the skeletons. *Current Anthropology* 48(2):301–314.

Bocherens, H. 2000. Preservations of isotopic signals (^{13}C, ^{15}N) in Pleistocene mammals. In *Biogeochemical approaches to paleodietary analysis.* Stanley H. Ambrose and M. Anne Katzenberg, eds. Pp. 65–88. Advances in Archaeological and Museum Science 5. New York: Plenum.

Borrero, L. A., and R. Barberena. 2006. Hunter-gatherer home ranges and marine resources: an archaeological case from southern Patagonia. *Current Anthropology* 47(5):855–867.

Budd, P., A. Millard, C. Chenery, and S. Lucy. 2004. Investigating population movement by stable isotope analysis: a report from Britain. *Antiquity* 78(299):127–141.

Cornejo, L., and L. Sanhueza. 2003. Coexistencia de cazadores recolectores y horticultores tempranos en la Cordillera Andina de Chile central. *Latin American Antiquity* 14(4): 389–407.

Cornejo, L., and J. Simonetti. 1997–1998. De rocas y caminos: espacio y cultura en los Andes de Chile central. *Revista Chilena de Antropología* 14:127–143.

Durán, E. 1980. Tagua Tagua II, nivel de 6130 años: descripción y relaciones. *Boletín del Museo Nacional de Historia Natural* 37:75–86.

Ehleringer, J. R., G. J. Bowen, L. A. Chesson, A. G. West, D. W. Podlesak, and T. E. Cerling. 2008. Hydrogen and oxygen isotope ratios in human hair are related to geography. *Proceedings of the National Academy of Sciences of the USA* 105(8):2788–2793.

Falabella, F., L. Cornejo, I. Correa, E. Latorre, M. Vásquez, and L. Sanhueza. Forthcoming. Los "escondrijos" en reparos rocosos de la zona de el Pangal y sus componentes culturales. Paper presented at the 17th Congreso Nacional de Arqueología Chilena, Valdivia, Chile, October 2006.

Falabella, F., and M. T. Planella. 1991. Comparación de ocupaciones precerámicas y agroalfareras en el litoral de Chile central. En *Actas XI Congreso Nacional de Arqueología Chilena. T.3.* Hans Niemeyer, ed. Pp. 95–112. Santiago: Museo

Nacional de Historia Natural, Sociedad Chilena de Arqueología.

Falabella, F., M. T. Planella, E. Aspillaga, L. Sanhueza, and R. H. Tykot. 2007. Dieta en sociedades alfareras de Chile central: aporte de análisis de isótopos estables. *Chungara, Revista de Antropología Chilena* 39(1):5–27.

Falabella, F., M. T. Planella, and R. H. Tykot. 2008. El maíz (*Zea mays*) en el mundo prehispánico de Chile central. *Latin American Antiquity* 19(1):25–46.

Falabella, F., and R. Stehberg. 1989. Los inicios del desarrollo agrícola y alfarero: zona central (300 AC a 900 DC). En *Prehistoria (Cap. XIV)*. J. Hidalgo, V. Schiappacasse, H. Niemeyer, C. Aldunate, and I. Solimano, eds. Pp. 95–311. Santiago: Editorial Andrés Bello.

Gajardo-Tobar, R. 1958–1959. Investigaciones acerca de las "Piedras con Tacitas" en la zona central de Chile. *Anales de Arqueología y Etnología, Universidad Nacional De Cuyo* XIV–XV:163–204.

Hedges, R. E. M., and L. M. Reynard. 2007. Nitrogen isotopes and the trophic level of humans in archaeology. *Journal of Archaeological Science* 34:1240–1251.

Hermosilla, N., L. Lavanderos, B. Saavedra, L. Vargas, and M. Carrasco. 2003. Uso del espacio en los períodos Alfarero Temprano y Tardío: análisis comparativo. *Actas Cuarto Congreso Chileno de Antropología* (2001) Tomo II: 1419–1426.

Jackson, D., and C. Thomas. 2000. El Arcaico de la comuna de Lampa, Chile central. *Actas Segundo Taller de Arqueología de Chile Central* (1993). http://www.arqueologia.cl/actas2/jacksonythomas.pdf.

Jenny, B., Blas L. Valero-Garcés, R. Urrutia, K. Kelts, H. Veit, P. G. Appleby, and M. Geyh. 2002. Moisture changes and fluctuations of the westerlies in Mediterranean central Chile during the last 2,000 years: the Laguna Aculeo record (33°50′S). *Quaternary International* 87:3–18.

Kaltwasser, J., A. Medina, and J. Munizaga. 1980. Cementerio del período Arcaico en Cuchipuy. *Revista Chilena de Antropología* 3:109–123.

Koch, P. L. 2007. Isotopic study of the biology of modern and fossil vertebrates. In *Stable isotopes in ecology and environmental science.* 2nd edition. R. Michener and K. Lajtha, eds. Pp. 99–154. Boston: Blackwell.

Levinson, A. A., B. Luz, and Y. Kolodny. 1987. Variations in oxygen isotopic compositions of human teeth and urinary stones. *Applied Geochemistry* 2:367–371.

Llagostera, A. 1989. Caza y pesca marítima (9000 a 1000 a.C.). In *Prehistoria (Cap. XIV)*. J. Hidalgo, V. Schiappacasse, H. Niemeyer, C. Aldunate, and I. Solimano, eds. Pp. 57–79. Santiago: Editorial Andrés Bello.

Longinelli, A. 1984. Oxygen isotopes in mammal bone phosphate: a new tool for paleohydrological and paleoclimatological research. *Geochimica et Cosmochimica Acta* 48(2): 385–390.

Luz, B., Y. Kolodny, and M. Horowitz. 1984. Fractionation of oxygen isotopes between mammalian bone-phosphate and environmental drinking water. *Geochimica et Cosmochimica Acta* 48:1689–1693.

Madrid, J. 1977. Ocupación indígena en el valle suprior del río Maipo. Tesis para optar al grado de Licenciado en Arqueología y Prehistoria. Santiago: Universidad de Chile.

Moser, H., C. Silva, W. Stichler, and L. Stowhas. 1972. Measuring the isotope content in precipitation in the Andes. *Proceedings of the Banff Symposium, UNESCO-WMO-IAHS* 1:15–23.

Núñez, L. 1983. *Paleoindio y Arcaico en Chile: diversidad, secuencia y procesos.* México City: Ediciones Cuicuilco.

Planella, M. T., L. Cornejo, and B. Tagle. 2005. Alero Las Morrenas 1: evidencias de cultígenos entre cazadores recolectores de finales del período Arcaico en Chile central. *Chungara* 37(1):59–74.

Planella, M. T., V. McRostie, C. Belmar, L. Quiroz, and G. Rojas. 2006. Descripción y análisis de granos de almidón de muestras de referencia vegetales (domésticas y silvestres) y muestras de artefactos arqueológicos en Chile central. *Informe Proyecto de Cooperación Internacional*, Fondecyt 7050165.

Quiroz, L., and C. Belmar. 2004. Estrategias de explotación de recursos vegetales: evidencia arqueobotánica de tres sitios de la región central de Chile: Radio Estación Naval, El Cebollar y Lonquén (E 80–4). *Chungara* Volumen Especial: 1109–1119.

Quiroz, D., and M. Sánchez. 2004. Poblamientos iniciales en la costa septentrional de la Araucanía (6.500–2.000 a.p.). *Chungara Volumen Especial* I:289–302.

Ramírez, J. M., N. Hermosilla, A. Jerardino, and J. C. Castilla. 1991. Análisis bio-arqueológico preliminar de un sitio de cazadores recolectores costeros: Punta Curaumilla-1, Valparaíso. *Actas XI Congreso Nacional de Arqueología Chilena. T.3.* Hans Niemeyer, ed. Pp. 81–93. Santiago: Museo Nacional de Historia Natural, Sociedad Chilena de Arqueología.

Richards, M. P., and R. E. M. Hedges. 1999. Stable isotope evidence for similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic coast of Europe. *Journal of Archaeological Science* 26(6):717–722.

Rozanski, K., and L. Araguás. 1995. Spatial and temporal variability of stable isotope composition of precipitation over the South American continent. *Bulletin Institut Francais d'Etudes Andines* 24(3):379–390.

Sanhueza, L. 1997. Relaciones llano-cordillera durante el período Agroalfarero Temprano en Chile central: una visión desde la cerámica. Tesis de grado. Santiago: Universidad de Chile.

Sanhueza, L., and F. Falabella. 2003. Las comunidades alfareras iniciales de Chile central: continuidades y cambios desde el arcaico tardío a las sociedades hortícolas y alfareras. *Actas IV Congreso Chileno de Antropología* II:1405–1410.

———. 1999–2000. Las comunidades alfareras iniciales en Chile central. *Revista Chilena de Antropología* 15:29–47.

Sanhueza, L., M. Vásquez, and F. Falabella. 2003. Las sociedades alfareras tempranas de la cuenca de Santiago. *Chungara* 35(1):23–50.

Schoeninger, M. J., M. J. De Niro, and H. Tauber. 1983. Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science* 220:1381–1383.

Schoeninger, M. J., M. J. Kohn, and J. W. Valley. 2000. Tooth oxygen isotope ratios as paleoclimate monitors in arid ecosystems. In *Biogeochemical approaches to paleodietary analysis,*. S. H. Ambrose and M. A. Katzenberg, eds. Pp. 117–140. Advances in Archaeological and Museum Science 5. New York: Plenum.

Schwarcz, H. P. 2000. Some biochemical aspects of carbon isotopic paleodiet studies. In *Biogeochemical approaches to paleodietary analysis.* S. H. Ambrose and M. A. Katzenberg, eds. Pp. 189–209. Advances in Archaeological and Museum Science 5. New York: Plenum.

Schwarcz, H. P., T. L. Dupras, and S. I. Fairgrieve. 1999. ^{15}N-enrichment in the Sahara: in search of a global relationship. *Journal of Archaeological Science* 26:629–636.

Schwarcz, H. P., L. Gibbs, and M. Knyf. 1991. Oxygen isotope analysis as an indicator of place of origin. In *Snake Hill: an investigation of a military cemetery from the War of 1812.* S. Pfeiffer and R. Williamson, eds. Pp. 263–268. Toronto: Dundurn.

Stehberg, R. 1978. El cementerio alfarero temprano de Chacayes, interior del Cajón del Maipo, Chile, datado en 430 años d.c. *Revista de Historia Natural (Actas Del IV Congreso de Arqueología Argentina)*, San Rafael 3(1/4):277–295.

Tieszen, L. L., E. Iversen, and S. Matzner. 1992. Dietary reconstruction based or carbon, nitrogen and sulfur stable isotopes in the Atacama desert, northern Chile. *Proceedings of the First World Congress on Mummy Studies* I:427–441. Cabildo de Tenerife: Museo Arqueológico y Etnográfico de Tenerife.

Tykot, R. H. 2004. Stable isotopes and diet: you are what you eat. In *Physics methods in archaeometry: proceedings of the International School of Physics "Enrico Fermi."* M. Martini, M. Milazzo, and M. Piacentini, eds. Pp. 433–444. Bologna: Societá Italiana de Fisica.

Villa-Martínez, R. 2002. Historia del clima y la vegetación de Chile central durante el holoceno: una reconstrucción basada en el análisis de polen, sedimentos, microalgas y carbón. Tesis doctoral, Universidad de Chile, Santiago.

White, C. D., M. W. Spence, F. J. Longstaffe, and K. R. Law. 2004. Demography and ethnic continuity in the Tlailotlacan enclave of Teotihuacan: the evidence from stable oxygen isotopes. *Journal of Anthropological Archaeology* 23(4): 385–403.

White, C. D., M. W. Spence, F. J. Longstaffe, H. Stuart-Williams, and K. R. Law. 2008. Geographic identities of the sacrificial victims from the Feathered Serpent pyramid, Teotihuacan: implications for the nature of state power. *American Antiquity* 13(2):217–236.